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ORIGINAL ARTICLE

Lumbosacral lordosis in fetal spine: genetic or mechanic parameter

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Abstract Many believe that the fetus spine had only one curvature from cranial to caudal which is a global kyphosis and that the lumbosacral lordosis appears with the erect posture. They agree that the sacrum of *Homo sapiens* is not positioned posteriorly at birth and that it is during the first few years that the sacrum, in humans, moves dorsally in relation with the progressive acquisition of erect posture and the ontogeny of bipedal locomotion. Nevertheless, there is no biometric study assessing these parameters in vivo in utero during the fetal life. Cross-sectional biometric study of the lumbosacral junction of the spine in in utero fetuses was to document the presence of a lumbosacral lordosis in the fetal population in utero long before standing and walking and its change during growth. Forty-five MRIs (magnetic resonance imaging) of fetuses aged of 23–40 weeks of gestation were analyzed. The measurements were performed on computerized MRI DICOM images using a professional software to calculate the curvature and radius of the lumbosacral junction. The presence or absence of visual lumbosacral lordosis was noted for each case. Correlation tests were performed in order to disclose a correlation between the gestational age and the curvature calculated. A test was considered significant for $P < 0.01$. There were 14 males, 17 females and 14 undetermined. All the curves (100%) showed mathematically the presence of a lordosis in the lumbosacral region. The visual lumbosacral lordosis was present in 60% of cases. The measurement of the lumbosacral curvature varies between -0.133 and $-0.033\ \mathrm{mm}^{-1}$ and a mean of $-0.054\ \mathrm{mm}^{-1}$ with a corresponding radius ranging from -7 to -303 mm with a mean of -18.7 mm. The statistical analysis showed no correlation between the gestational age and the lumbosacral curvature ($R^2 = 0.11$). The hypothesis of increased lumbosacral lordosis with gestational age is rejected. It is difficult to accurately determine the role played separately by genetics and by erect posture. A visual lumbosacral lordosis was noted in 60% of cases with mean radius of -18.6691 mm. This lordosis was not correlated statistically to gestational age which means that it is not related to growth and might be genetically determined. Mechanical factors may play a major role in the determination of the shape of the growing pelvis. One can ask if the pelvis morphology is genetically determined or if it is mechanically determined under muscular and ligamentous stresses. This study shows that the sacrum of human fetuses is oriented posteriorly mathematically in 100% of cases, and in 60% of cases based on the morphologic appearance of the lumbosacral junction. So beside the effect of progressive acquisition of erect posture and bipedalism in determining the formation of lumbosacral angle, we believe that genetics play an important role in the formation of the lumbosacral angle.

Keywords In utero MRI · Lumbosacral lordosis · Curvature · Genetic parameter · Fetal spine

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Introduction

Development of the vertebral column can be divided into three periods. The first of these is membranous development. The second stage is known as chondrification. In the final stage, the chondral skeleton ossifies to complete the formation of the vertebrae. Ossification of typical vertebrae begins during the embryonic period and usually ends by the 25th year [4, 26].

Dimeglio et al. [4] believe that the fetus spine had only one curvature from cranial to caudal which is a global kyphosis and that the lumbosacral lordosis, closely linked to lumbar lordosis, appears with the erect posture.

For Abitbol [1], the development of the lumbosacral angle is related to the progressive acquisition of erect posture and the ontogeny of bipedal locomotion. He agrees with Schultz [23] that the sacrum of *Homo sapiens* is not positioned posteriorly at birth and that it is during the first few years that the sacrum, in humans, moves dorsally.

Several studies have shown that the sagittal pelvic morphology greatly influences the standing balance in normal adults, especially by regulating the lumbar lordosis [11, 14, 15, 20, 22, 25].

The course of the pelvic incidence, described by Legaye et al. [14], has been studied from acquisition of walking to adulthood. The pelvic incidence remains relatively constant during childhood [17, 18]. Thereafter the pelvic incidence increases during adolescent until reaching its maximum value in adulthood [3, 19]. This anatomic parameter with the lumbar lordosis determines the pelvic orientation in the sagittal plane. The biometric study, done by Jouve et al. [16], evaluated the pelvic incidence during fetal life in postmortem. He thinks that the spinal allometry could be considered as a genetically determined parameter and that the changes of pelvic incidence through growth could be caused by mechanical stress factors that are able to modify a primary anatomical shape that could have been genetically determined.

The purpose of the study is to demonstrate the presence of a lumbosacral lordosis in utero before bipedalism and that the lumbosacral angle is not simply mechanically acquired during the time the human infant is learning to stand upright and walk.

Previously, knowledge of the spine development has been based predominantly on roentgenographic study [2, 6, 8–10, 21]. However, measurements based on roentgenographic study suffer from magnification and do not distinguish vertebral body growth from disk growth. We chose to do the measurements on in utero MRIs (magnetic resonance imaging). The measurements made on MRI did not have the magnification effect. Moreover, growth of the vertebral body can be assessed separately from growth of the disk space. MRI allows visualization of the ossified portion of the vertebrae as well as the cartilaginous portion of the vertebrae.

Materials and methods

Data were collected from the archive of radiology at Nord hospital in Marseille. One hundred fifty-six MRI of pregnant women were studied between 2002 and 2006. These MRI were done for detection of intrauterine abnormalities essentially visceral abnormalities. We noted the presence of

- digestive abnormalities such as diaphragmatic hernia, esophageal duplication, gastroschisis, omphalocele, duodenal atresia, intestinal atresia, ascites, etc.,
- urogenital abnormalities such as renal multicystic dysplasia, ovary cyst, sexual ambiguity, vesicoureteral reflux, hydronephrosis, hydrocolpos, etc.,
- other abnormalities such as femur hypoplasia, hydramnios, etc.

These MRIs were analyzed to study the spine of the fetuses even though they were not done for this reason. Forty-five MRIs out of 156 were exploitable for the study of the spine. The criteria to choose these 45 MRIs are essentially the visibility of the spine in totality on one slide and the motionless of the mother and the fetus.

All the MRIs were performed at Nord hospital MR center on 1.5-T superconducting magnet. A flexible, phased-array surface coil was used in all fetuses. Single-shot fast spin-echo sequences and fast field sequences (true-FISP, balanced FFE) were used to explore the sagittal plane.

The MRIs were studied to measure the different curves in the fetal spine, namely the lumbar and the sacral curve. The aim was to demonstrate the presence of an angle between the lumbar and the sacral curvature. All of the measurements were performed on computerized MRI DICOM images, using SigmaScan pro5®, a professional SPSS® software. Measurement algorithms designed in order to calculate the curvature and radius were developed using Matlab®, the Mathworks, USA.

The curvatures of the spine were measured as follows:

1. The operator draw a few key points located at the posterior part of the vertebral body, from which a cubic *spline* was interpolated (Fig. 1).
2. L5/S1 and T12/L1 disks centers were digitized, yielding to the segmentation of the different parts of the spine.
3. The operator was asked to click a point anteriorly to the spine, which allows for determination of the sign of the curvatures.
4. Three consecutive points of the spline were considered to fit a circle, from which curvature and radius were calculated along the spine (Fig. 2).

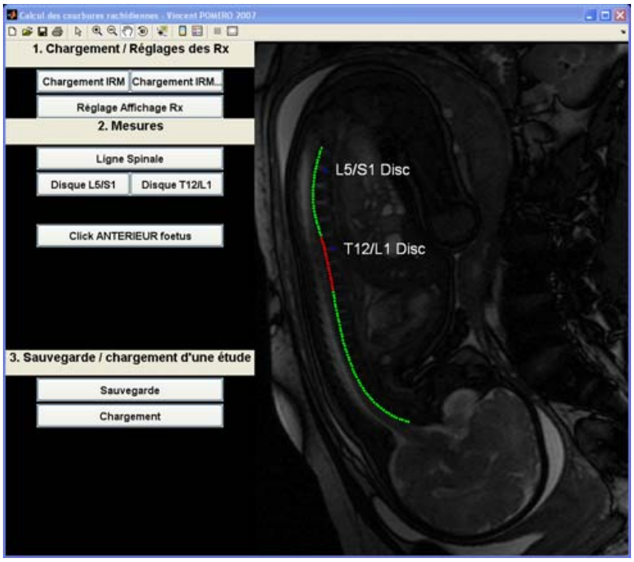

Fig. 1 Steps in measuring spine curvature

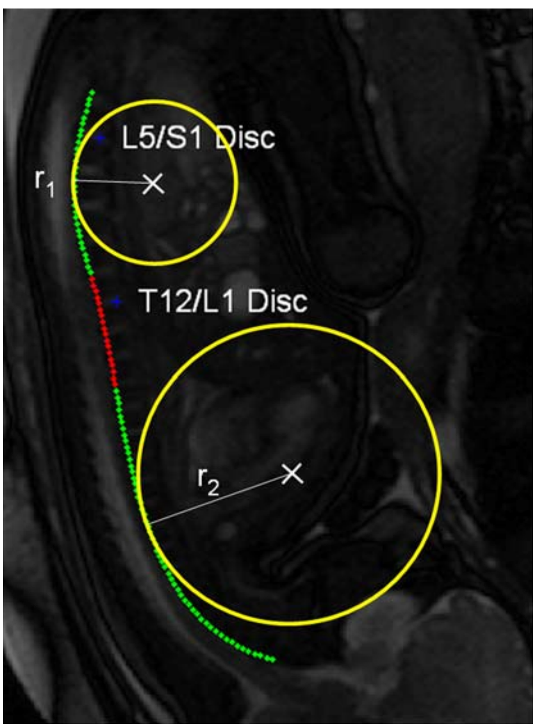

Fig. 2 Illustration of the way radius and curvature were calculated along the spine, using three consecutive points of the spline representing the spine. The radius r_1 of the upper circle which fits the points of the spline at this level is smaller than the radius r_2 of the lower circle, yielding to a larger curvature (as curvature is the reciprocal of the radius)

In each case, a curvature and a corresponding radius were calculated from the data collected as previously described. The presence or absence of visual lumbosacral lordosis was noted for each case as shown below.

Correlation tests were performed in order to disclose a correlation between the gestational age and the curvature calculated. A test was considered significant for $P < 0.01$.

Results

The study included 45 fetuses aged from 23 to 40 gestational weeks.

There were 14 males, 17 females and 14 undetermined.

The pregnant women were aged from 20 to 45 years with a mean of 31 years (Fig. 3).

The fetuses' age varies between 23 and 40 gestational weeks with a mean of 32 gestational weeks (Fig. 4).

The gender of the fetuses was identified in 31 cases out of 45 (69%) (Fig. 5).

All the curves (100%) showed mathematically the presence of a lordosis in the lumbosacral region (the *minus* sign below), but it has been remarked that in some cases this lordosis was visually very slight and even near straight line. Therefore, in opposition to mathematical calculation, we added what we called the visual lumbosacral lordosis. It described a clear lordosis in the lumbosacral region that can be identified in opposition of the complete round back of the fetus.

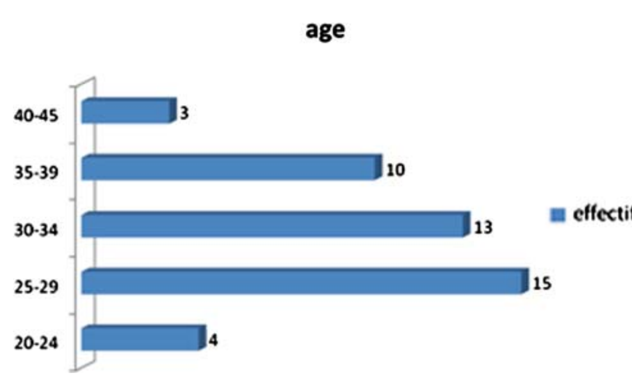

Fig. 3 Age of the pregnant women

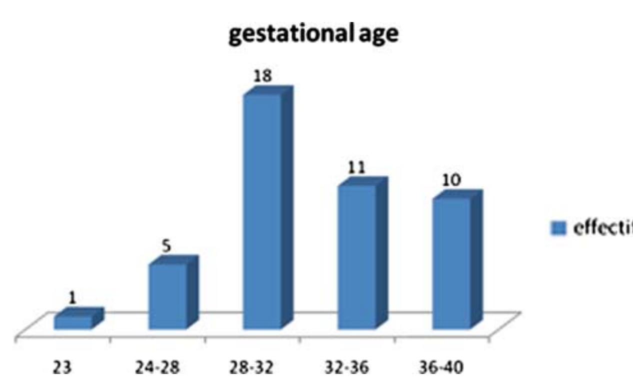

Fig. 4 Age of the fetuses

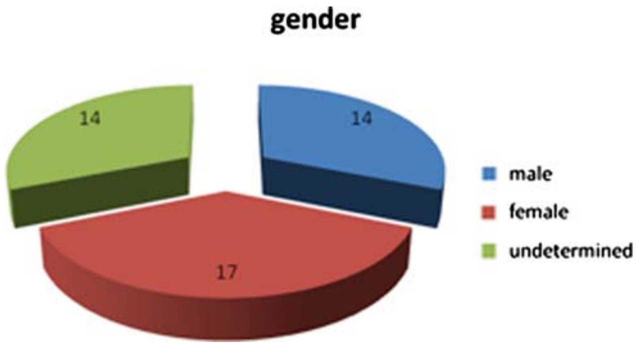

Fig. 5 Gender of the fetuses

Table 1 Visual lumbosacral lordosis

Visual lumbosacral lordosis	Effective	Frequency (%)
Presence	27	60
Absence	11	24.5
Doubtful	7	15.5

The visual lumbosacral lordosis was present in 27 cases, absent in 11 cases and doubtful in 7 cases (Table 1).

The measurement of the lumbosacral curvature varies between -0.133 and -0.033 mm^{-1} (minus for lordosis and plus for kyphosis) and a mean of -0.054 mm^{-1} with a corresponding radius ranging from -7 to -303 mm with a mean of -18.7 mm.

Figure 6 shows the presence of a visual lumbosacral lordosis with a curvature of -0.055 mm^{-1} and a radius of -18 mm.

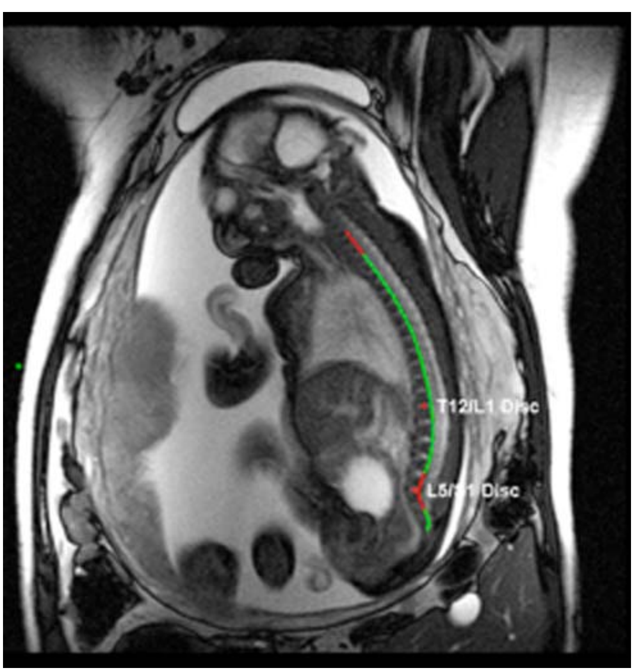

Fig. 6 Fetus at 32 weeks of gestation with a visual lumbosacral lordosis. Curvature = -0.055 mm^{-1}; radius = -18 mm

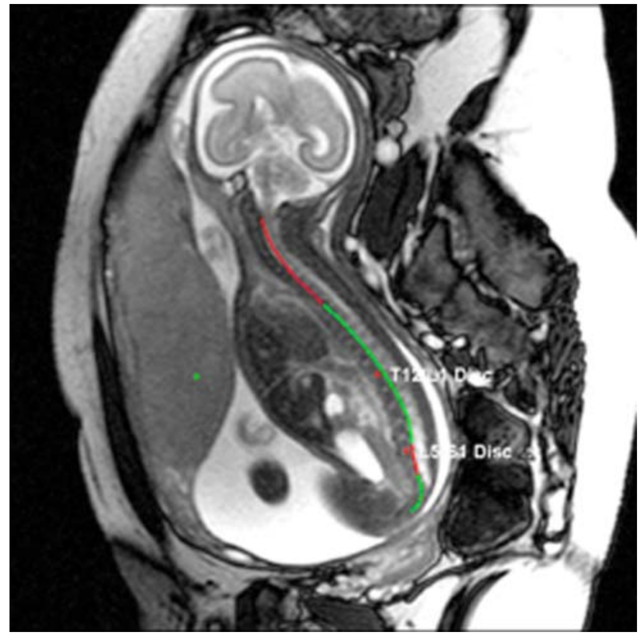

Fig. 7 Fetus at 25 weeks of gestation without visual lumbosacral lordosis. Curvature = -0.022 mm^{-1}; radius = -44 mm

Figure 7 shows the absence of lordosis at the lumbosacral region with a curvature of -0.0225 mm^{-1} and a radius of -44 mm.

Figure 8 shows an example of doubtful lumbosacral lordosis with a curvature of -0.033 mm^{-1} and a radius of -30.30 mm.

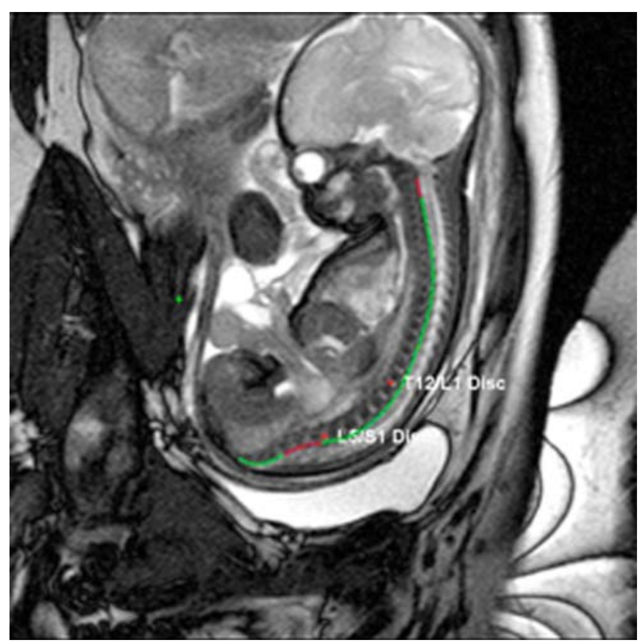

Fig. 8 Fetus at 32 weeks of gestation with a doubtful visual lumbosacral lordosis. Curvature = -0.032 mm^{-1}; radius = -30 mm

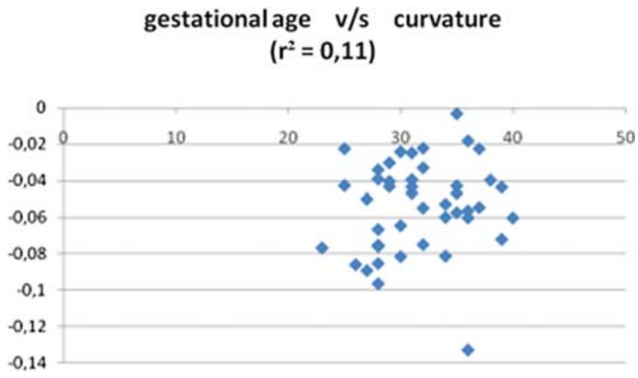

Fig. 9 Correlation between gestational age and lumbosacral curvature

The statistical analysis showed no correlation between the gestational age and the lumbosacral curvature ($R^2 = 0.11$) as shown in the Fig. 9, which means that the hypothesis of increased lumbosacral lordosis with gestational age is rejected.

Discussion

This is a cross-sectional study that describes the normative data of the sagittal plane in fetal population and documents the evolution of sagittal alignment with growth using in utero MRI. The purpose of the study is to demonstrate the presence of a lumbosacral lordosis in utero before bipedalism and that the lumbosacral angle is not simply mechanically acquired during the time the human infant is learning to stand upright and walk.

The lumbosacral angle (Fig. 10), as described by Abitbol [1], is formed by a perpendicular to the lumbar line (drawn on the anterior surface of L3) and a perpendicular to the sacral line (drawn on the anterior surface of the sacrum). A line drawn tangentially over the superior surface of the sacrum divides the LSA into lumbar angle and sacral angle. The former represents the angulation of the different intervertebral spaces, and the latter represents the posterior tilt of the anterior surface of the sacrum.

Other parameters have been used to describe the pelvic morphology based on standing lateral radiographs. These morphologic parameters are specific to each individual and unaffected by the three-dimensional orientation of the pelvis [5].

It is difficult to accurately determine the role played separately by genetics and by erect posture; the data presented by Abitbol [1] point to the importance of the role played by the latter. In our survey, we tried to determine the role played exclusively by genetics in the formation of the lumbosacral lordosis. For this purpose, we analyzed the

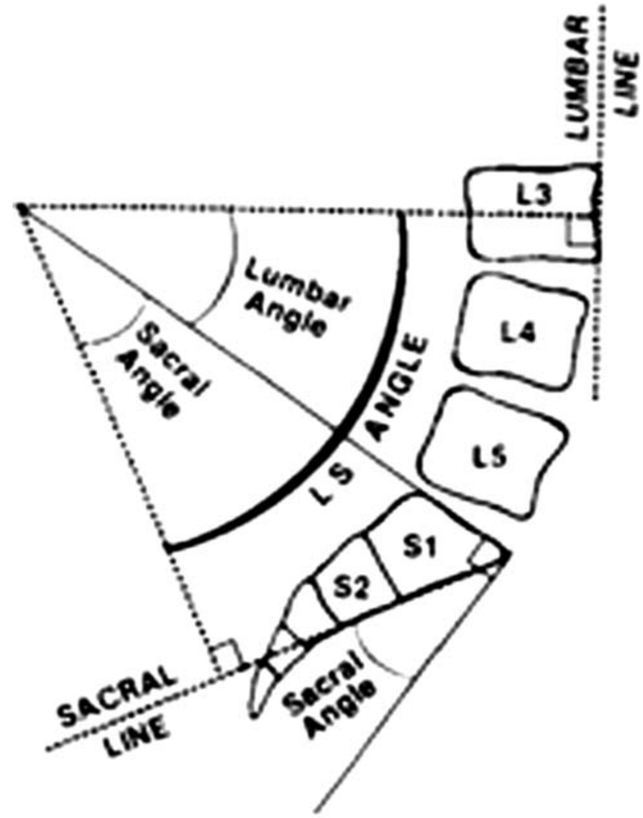

Fig. 10 Lumbosacral angle (by Abitbol [1])

lumbosacral region of fetuses in utero, thus eliminating the biomechanical component of erect posture.

For this reason, in utero MRI of 45 fetuses aged between 23 and 40 weeks of gestation were reviewed and analyzed.

In utero MRI has entered the clinical arena during the last decade. The expected improved anatomical and contrast resolution of MR should, theoretically, provide additional information when compared to ultrasonography imaging. The latter remains the primary imaging modality for evaluating the developing fetus, and can distinguish normal from abnormal spine development, and provide valuable information about spinal anomalies. MRI of the fetal spine is complementary, in fact often superior, to ultrasonography for assessment of suspected spinal malformations [24]. One of the limitations of fetal MRI is that of fetal motion. Because sedation for fetal MRI is not used, it was only after the advent of rapid T2-weighted pulse sequences (where a single image can be acquired in less than 1 s) that fetal MRI became embraced as a clinically important imaging technique.

Additional limitations of fetal MRI include the small size of the structure being imaged (usually the fetal brain or spine) and the large distance between the fetus (which lies within the uterine cavity) and the receiver coil (which lies on the mother's abdomen and pelvis). These limitations are currently being overcome with advances in coil design, such as parallel imaging with increasing number of channels, but are still important factors contributing to the inherent limitations of fetal MRI with young gestational age fetuses. The American College of Radiology white paper on MR safety published in 2002 states that "Pregnant patients can be accepted to undergo MR images at any stage of pregnancy if, in the determination of a Level Two MR Personnel—designated attending radiologist, the risk-benefit ratio to the patient warrants that the study be performed." [13] However, because of the potential risk of MRI to the developing fetus and the current limitations of fetal MRI, it is prudent to wait until after the first trimester before performing fetal MRI. In fact, it is *preferable* to wait until at least gestational week 22 to minimize the difficulties created by the small size and excessive motion of younger fetuses.

Therefore, all the MRIs in this survey are done after 23 weeks of gestation. Intravenous contrast is also not recommended in fetal MRI because of the potential risk to the fetus.

A visual lumbosacral lordosis was noted in 60% of cases with mean radius of -18.6691 mm. This lordosis was not correlated statistically to gestational age, which means that it is not related to growth and might be genetically determined.

Abitbol [1] showed that the lumbosacral angle increases from an average of 20° at birth to an average of 70° at the age of 5 years; it remains at that level thereafter. His study also demonstrates that the formation of the lumbosacral angle is not related to increasing age, height, or weight. This absence of correlation with age after birth has also been true before birth in the fetal life as it appears in this study with a correlation coefficient of 0.11 between the lumbosacral lordosis and the gestational age.

Dimeglio et al. [4] believe that the fetus spine had only one curvature from cranial to caudal which is a global kyphosis and that the lumbosacral lordosis, closely linked to lumbar lordosis, appears with the erect posture.

For Abitbol [1], obstetrical requirements do not seem to play any major role in the formation of the lumbosacral angle. Rather, it appears that the development of the lumbosacral angle is related to the progressive acquisition of erect posture and the ontogeny of bipedal locomotion. He agrees with Schultz [23] that the sacrum of *Homo sapiens* is not positioned posteriorly at birth and that it is during the first few years that the sacrum, in humans, moves dorsally.

Mechanical factors may play a major role in the determination of the shape of the growing pelvis. In utero, the fetal position is characterized by a flexion of hip and spine. After birth, hips are extended, and the lumbar spine is placed in extension/lordosis. These two features are characteristic of bipedalism. Some strong mechanical stresses are generated and applied on hips, pelvis, and lumbosacral junction. These stresses may have a strong influence on the shape of the pelvis.

One can ask if the pelvis morphology is genetically determined or if it is mechanically determined under muscular and ligamentous stresses. In previous series, we pointed out that some elements of the limb skeleton are fixed in their shape during all the fetal life [12]. As an example, the trochlear femoral groove was shown to be fixed in its shape during all the fetal life [7]. Conversely, other elements were shown to be strongly correlated with age. Femoral anteversion, for example, regularly increases over time during the fetal life [12], is maximal at birth, and regularly decreases over time until 11 years of age after birth, and then stabilizes to its definite adult value.

This study shows that the sacrum of human fetuses is oriented posteriorly mathematically in 100% of cases, and in 60% of cases based on the morphologic appearance of the lumbosacral junction. So beside the effect of progressive acquisition of erect posture and bipedalism in determining the formation of lumbosacral angle, we believe that genetics play an important role in the formation of the lumbosacral angle.

Conclusion

This study showed that the fetal spine is not formed just by one curvature cranial to caudal and that the sacrum is tilted posteriorly at birth. These findings are not to imply that upright posture and locomotion play no role in reshaping the pelvis, in fact the pelvic incidence greatly changes through growth [16]. During the fetal period the pelvic incidence seems to decrease and after birth, until growth is over, the pelvic incidence increases. These changes could be caused by mechanical stress factors that are able to modify a primary anatomical shape that could have been genetically determined. On the other side, some elements of the limb skeleton are fixed in their shape during all the fetal life, like the trochlear groove [12]. Likely, the lumbosacral lordosis, present at birth, does not change with growth. Based on these observations, one can think that the sacrum's posterior tilt could be considered as a genetically determined parameter.

Conflict of interest statement None of the authors has any potential conflict of interest.

References

1. Abitbol MM (1987) Evolution of the lumbosacral angle. Am J Phys Anthropol 72:361–372. doi:10.1002/ajpa.1330720309

2. Bagnall KM, Harris PF, James RM (1977) A radiographic study of the human fetal spine. 2. The sequence of development of ossification centers in the vertebral column. J Anat 124:791
3. Descamps H, Commare-Nordmann MC, Marty C et al (1999) Modification of pelvic angle during the human growth. Biom Hum Anthropol 17:59–63 in French
4. Dimeglio A, Bonnel F (1990) Le rachis en croissance. Springer, Paris
5. Duval-Beaupère G, Schimdt C, Cosson P (1992) A barycentremetric study of the sagittal shape of spine and pelvis: the conditions required for an economic standing position. Ann Biomed Eng 20:451–462. doi:10.1007/BF02368136
6. Flecker H (1942) Time of appearance and fusion of ossification centers as observed by roentgenographic methods. AJR Am J Roentgenol 47:97
7. Glard Y, Jouve JL, Garron E et al (2005) Anatomic study of femoral patellar groove in fetus. J Pediatr Orthop 25:305–308. doi:10.1097/01.bpo.0000161099.46339.eb
8. Glenn OA, Barkovich J (2006) Magnetic resonance imaging of the fetal brain and spine: an increasingly important tool in prenatal diagnosis: part 1. AJNR Am J Neuroradiol 27(8):1604–1611
9. Glenn OA, Barkovich J (2006) Magnetic resonance imaging of the fetal brain and spine: an increasingly important tool in prenatal diagnosis: part 2. AJNR Am J Neuroradiol 27(9):1807–1814
10. Griffiths PD, Widjaja E, Paley MN, Whitby EH (2006) Imaging the fetal spine using in utero MR: diagnostic accuracy and impact on management. Pediatr Radiol 36(9):927–933
11. Jackson RP, Hales C (2000) Congruent spinopelvic alignment on standing lateral radiographs of adult volunteers. Spine 25:2808–2815. doi:10.1097/00007632-200011010-00014
12. Jouve JL, Glard Y, Garron E et al (2005) Anatomical study of the proximal femur in the fetus. J Pediatr Orthop B 14:105–110
13. Kanal E, Borgstede JP, Barkovich AJ et al (2002) American College of Radiology white paper on MR safety. AJR Am J Roentgenol 178:1335–1347
14. Legaye J, Duval-Beaupère G, Hecquet J et al (1998) Pelvic incidence: a fundamental pelvic parameter for three-dimensional regulation of spinal sagittal curves. Eur Spine J 7:99–103. doi:10.1007/s005860050038
15. Legaye J, Hecquet J, Marty C et al (1993) Sagittal equilibration of the spine: relationship between pelvis and sagittal spinal curves in the standing position. Rachis 5:215–226
16. Louis ML, Jouve JL, Adalian P, Pomero V, Glard Y (2009) Fetal spine and pelvic incidence growth: biometric analysis (in press)
17. Mac-Thiong JM, Berthonnaud E, Dimar JR, Betz RR, Labelle H (2004) Sagittal alignment of the spine and pelvis during growth. Spine 29(15):1642–1647
18. Mangione P, Gomez D, Senegas J (1997) Study of the course of the incidence angle during growth. Eur Spine J 6:163–167. doi:10.1007/BF01301430
19. Mangione P, Sénégas J (1997) Normal and pathologic sagittal balance of the spine and pelvis. Rev Chir Orthop Repar Appar Mot 83:22–32
20. Marty C, Boisaubert B, Descamps H et al (2002) The sagittal anatomy of the sacrum among young adults, infants, and spondylolisthesis patients. Eur Spine J 11:119–125. doi:10.1007/s00586-001-0349-7
21. O'Rahilly R, Meyer DB (1956) Roentgenographic investigation of the human skeleton during early fetal life. AJR Am J Roentgenol 76:455
22. Rajnics P, Pomero V, Templier A et al (2001) Computer-assisted assessment of spinal sagittal plane radiographs. J Spinal Disord 14:135–142. doi:10.1097/00002517-200104000-00008
23. Schultz AH (1961) Vertebral column and thorax. Primatologica, 4. Liefer 5:1–66
24. Simon EM (2004) MRI of the fetal spine. Pediatr Radiol 34:712–719. doi:10.1007/s00247-004-1245-1
25. Vaz G, Roussouly P, Berthonnaud E et al (2002) Sagittal morphology and equilibrium of pelvis and spine. Eur Spine J 11:80–87. doi:10.1007/s005860000224
26. Widjaja E, Whitbi EH, Paley MNJ, Griffiths PD (2006) Normal fetal lumbar spine on postmortem MR imaging. AJNR Am J Neuroradiol 27:553–559